Neogene Molluscan Faunas in the Japanese Islands: An Ecologic and Zoogeographic Synthesis

BY

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(8 Text figures)

INTRODUCTION

A VAST AMOUNT OF INFORMATION on the Japanese Neogene molluscan faunas has been accumulated since the late Professor Matajiro YOKOYAMA first described the Neogene mollusks from the Miura Peninsula, south of Tokyo, in 1920. In 1939, OTUKA outlined the Cenozoic marine and terrestrial faunas in Japan. He recognized two or three marine faunal provinces and showed different faunal sequences for each province. His synthesis had a marked influence on later work. Since then, many investigators have tried to synthesize the historic and geographic distributions of the Neogene mollusks in Japan. Some of these syntheses are, however, biostratigraphically oriented with little attention to the environmental background of the faunas (e.g., IKEBE, 1954; ASANO & HATAI, 1967), and others are geographically, stratigraphically, or taxonomically limited (e.g., KOTAKA, 1958, 1959; MASUDA, 1962; UOZUMI, 1962; CHINZEI, 1963; NODA, 1966; ITOIGAWA & SHIBATA, 1973). MASUDA (1973) discussed the geographic and stratigraphic distributions of the principal molluscan species in Japan, and divided the Japanese Neogene into 5 stratigraphic units.

In this paper I intend to present a general picture of historic and geographic changes of the Japanese Neogene molluscan faunas in view of ecologic characters of the faunal constituents, and their local and regional distributions.

The Neogene deposits of the Japanese Islands exhibit a major cycle of sedimentation. The cycle began in the early middle Miocene with rapid subsidence followed by gradual filling of the sedimentary basins. This general tendency was modified by local up- and down-movements in both basins and area of provenance. The geographic and stratigraphic distributions of the benthic molluscan faunas were primarily controlled by the history of sedimentation, and the characteristics of the water masses surrounding the Japanese Islands. Ecologically analogous associations, or fossil communities, occur at distinct stratigraphic levels where similar environmental conditions repeatedly appeared.

The analogous associations consist of different species belonging to the same genus or to allied genera whose ecologic requirements were essentially the same. They are found in the same sedimentary facies, such as offshore muddy facies, fine-grained sand facies of shallow embayments etc., at different horizons in the different areas. Thus the analogous relationships of these associations may be compared with ecologically parallel relationship observed among the Recent marine communities (THORSON, 1957).

Based on this repetition, the Neogene molluscan faunas of Japan can be grouped into 4 faunas of different ages. These faunas represent 4 phases in the historical change of our Neogene Mollusca. They are the early Miocene fauna (occurring somewhere between 26 and 16 my), the early middle Miocene fauna (c. 16-14 my), the late Miocene fauna (12-5 my), and the Pliocene to early Pleistocene fauna (5-1 my). The late Pleistocene and Recent faunas may be regarded as a 5th fauna and represent the latest stage of our faunal history.

On the other hand, the faunas of two different water systems, warm and cold, are recognized throughout the Neogene as well as today. The ecologically analogous relationships are also observed between the warm and cold water fossil faunas. By tracing changes in faunal characters we can follow the sequential shift of water masses around the Japanese Islands.

The chronology of the molluscan faunas and fossiliferous strata is based on the correlation table compiled by IKEBE *et al.* (1972), and revised according to later information. The correlation was made principally on the basis of planktic foraminiferal biostratigraphy supplemented by the data from other microbiostratigraphy and radiometric dating. Since the molluscan fossils are frequently found in the shallow water facies, their chronologic positions are not always determinable by planktic foraminifers. In such cases, the fossiliferous beds were placed chronologically based on local stratigraphic relationships and other indirect evidence.

EARLY MIOCENE FAUNAS

The early Miocene deposits are of limited distribution in the Japanese Islands, and their chronostratigraphy has not been established. The molluscan faunas also have not been very well documented. The faunas are associated with a minor transgression which was antecedent to and independent from the major middle to late Miocene transgression.

In northern Kyushu, a marine formation, the Ashiya Group, overlies thick coal-bearing formations of Paleogene age. The Group contains a shallow water molluscan fauna, the Ashiya fauna. The geologic age of the Group has been regarded by some as late Oligocene, by others as early Miocene. Recent studies have revealed that in the Nichinan area of southern Kyushu (Loc. 3, Figure 1), mollusks in common with the Ashiya Fauna are associated with the early Miocene planktic foraminifers, *Globigerinita dissimilis, Globigerina hohri,* and a few others (Shuto, 1963).

Medium-grained sandstone at the type locality of the Group (Loc. 1), is rich in mollusks, *Glycymeris cisshuensis, Solen connectens, Dosinia chikuzenensis, Pitar matsumotoi, Lucinoma nagaoi* and other suspension feeding bivalves (Shuto & Shiraishi, 1971). The association may represent the sandy bottom community of a shallow sea. Black sandy mudstone of the Ashiya Group in the Kottoi area (Loc. 2) contains *Venericardia subnipponica* and *Angulus maximus* with *Cultellus izumoensis, Acila ashiyaensis,* and *Saccella* sp. (Okamoto, 1970). They are associated with lenses of *Crassostrea* sp. *Batillaria takeharai* is found in sandstone around the oyster banks. The *Venericardia-Angulus* association may be a member of a subtidal muddy bottom community of an embayment. *Crassostrea* and *Batillaria* may represent an associated intertidal community.

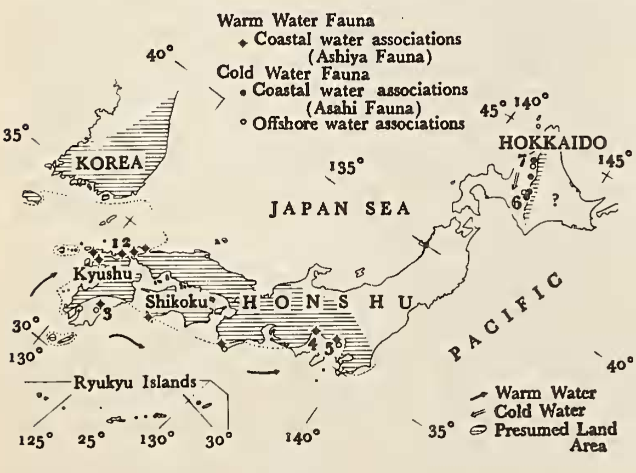


Figure 1

Distribution of the early Miocene molluscan faunas and presumed paleogeography of Japan during the early Miocene. Numerals indicate the fossil localities mentioned in the text; 1: Ashiya; 2: Kottoi; 3: Nichinan; 4: Moriya-yama; 5: Chichibu; 6: Asahi; 7: Chikubetsu

A molluscan fauna, which has been regarded as early Miocene, is known from the Chichibu Basin (Loc. 5; Kanno, 1960) and the Moriya area (Loc. 4), both in central Honshu. They are different in species composition from the Ashiya Group except for some common species, such as *Pitar matsumotoi, Dosinia chikuzenensis.* The fauna is characterized by *Anadara chichibuensis, Acila submirabilis, Venericardia tokunagai, Dosinia chikuzenensis,* and other coastal water sandy bottom bivalves. The stratigraphic relationship between the Chichibu-Moriya and the Ashiya Faunas is uncertain.

The Ashiya Fauna and the Chichibu-Moriya Fauna were most probably associated with warm water judging by the lack of apparently northern species and by the common or dominant occurrence of such warm water genera as *Anadara, Pitar,* and *Dosinia.*

Little is known about the offshore associations of early Miocene age. *Portlandia tokunagai, P. watasei* and some other nuculanid bivalves with *Periploma besshoensis* and *Macoma optiva* have been reported from several places along the Pacific coast including the Chichibu Basin in the mudstone referred to the lower Miocene. No reliable data, however, have been available on their bathymetric ranges and on the habitat relationship between the sandy shallow water faunas. Since *Portlandia tokunagai* and *P. watasei* are known from Sakhalin and Kamchatka (Gladenkov, 1974), these species probably lived in the cold water areas. The northern species tend to live at progressively greater depths toward the south, a relationship that exists in the present-day marine environment. In the Recent environment, a submerged tongue of cold water, the Oyashio Undercurrent, has been recognized under the surface Kuroshio Current at about 300 to 1000 m off the east coast of central Honshu. The tongue brings benthic and planktic subarctic species southward as exemplified by Okutani (1972). It is natural to infer that *P. tokunagai* and its associated species extended their distribution southward into deep water by means of the cold water undercurrent.

Occurrence of a shallow cold water molluscan fauna, named the Asahi Fauna, is known in central Hokkaido (Loc. 6). The fauna has been assigned to the early Miocene. No positive evidence, however, has been given on the geologic age of the fauna. It is contained in the Asahi Formation, the basal part of the Neogene marine sequence in central Hokkaido (UOZUMI, 1966; KANNO *et al.*, 1968). The formation yields *Mytilus tichanovitchi* associated with *Peronidia t-matsumotoi, P. elongata, Spisula onnechiuria, Thracia asahiensis, Tectonatica ezoana,* and other less abundant species. A similar association was reported from the Sankebetsu Formation in the Chikubetsu area of northwestern Hokkaido (Loc. 7), although *M. tichanovitchi* was not found there (KANNO & MATSUNO, 1960). The generic composition as well as the characters of the contained sediments indicate that the association represents a coastal water fauna.

The Asahi Fauna is quite different in species composition from the Ashiya Fauna as well as from the overlying early middle Miocene subtropical fauna which will be mentioned later. The species of the Asahi Fauna are limited in their distribution to Hokkaido or farther north. *Mytilus tichanovitchi* is reported from northern Sakhalin and Kamchatka (e.g., MAKIYAMA, 1934; GLADENKOV, 1974). The association is thus considered to represent a cold water fauna. The offshore type *Portlandia tokunagai* association is also found in the muddy facies of the Asahi and the Sankebetsu Formations.

EARLY MIDDLE MIOCENE FAUNAS

The early middle Miocene was a turning-point in the Japanese Neogene history. It was the start of geosynclinal sinking in Northeast Japan and along the Japan Sea coast, and the start of transgression onto the denuded hilly lands in the central part and on the Pacific coast of Southwest Japan. Shallow marine sediments cover the subaerial volcanic and clastic deposits, or the pre-Tertiary rocks.

The transgressive marine deposits contain abundant molluscan and other benthic faunas of shallow water type. The faunas are dominated by tropical and subtropical elements and they spread over most of the Islands (Figure 2). No true reef facies have been found in the main Japanese islands. The cold water fauna occurs only in northern Hokkaido, and the offshore associations in northern and central Honshu and Hokkaido.

Tropical molluscan associations were described by TSUDA (1960) from the Yatsuo area (Loc. 13), on the Japan Sea coast of central Honshu. In the Yatsuo area poorly sorted, dark grey muddy sandstone interdigitates with the conglomerate of deltaic facies. The sandstone contains *Geloina stacki, G. yamanei, Anadara daitokudoensis, Telescopium schenki, Vicarya yokoyamai, Cerithidea yatsuoensis* and other gastropods and a few bivalves. The association is comparable with the present-day mangrove swamp community (OYAMA, 1950), and indicative of the tropical nature of the early middle Miocene faunas. The same *Geloina* association was reported from the Shobara area in western Honshu (Loc. 9).

Other tropical mollusks were reported from the Ogurui area (Loc. 10; KOBAYASHI & HORIKOSHI, 1958). They are *Globularia nakamurai, Conus* cf. *jenkinsi, Rochia japonica, Turbo* cf. *ticaonica,* and the nautiloid *Aturia minoensis.* The gastropods are all equatorial genera that live on clean sandy bottoms facing an open sea. *Globularia nakamurai* was also found in the Shobara area (Loc. 9).

The characteristic elements of the mangrove swamp community, *Geloina* and *Telescopium,* are restricted to central and western Honshu, while the other species, such as *Anadara* and *Vicarya,* are known over the Japanese Islands as far north as southern Hokkaido. In Okushiri Island, Hokkaido (Loc. 18), *Anadara daitokudoensis, Soletellina minoensis, Vicaryella notoensis, Vicarya yokoya-*

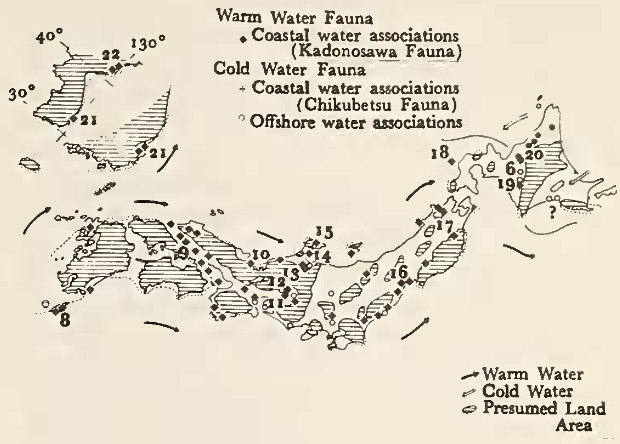


Figure 2

Distribution of the early middle Miocene molluscan faunas and presumed paleogeography of Japan during the early middle Miocene. Numerals indicate the fossil localities mentioned in the text; 8: Tanega-shima; 9: Shobara; 10: Ogurui; 11: Morozaki; 12: Mizunami; 13: Yatsuo; 14: Nanao; 15: northern tip of the Noto Peninsula; 16: Moniwa near Sendai; 17: Kadonosawa; 18: Okushiri Island; 19: Takinoue; 20: Uryu; 21: Gampo; 22: Myonchon *mai,* and some other species are found in dark grey, fine-grained sandstone, associated with oyster banks (Uozumi & Fujie, 1966). The composition of the association is typical of the *Anadara-Vicarya* association found in other areas of Japan, and is an example of a subtropical tidal flat community.

The habitats of subtropical coastal water communities and their areal distribution were reconstructed in the Kadonosawa Basin of northern Honshu (Loc. 17). In this basin, the basal bed of the marine Kadonosawa Formation was deposited in a small U-shaped embayment (Figure 3). Five autochthonous molluscan associations have been distinguished in this basal bed (Chinzei & Iwasaki, 1967).

The black muddy sandstone distributed in the bayhead and the marginal parts contains *Batillaria yamanarii* and *Macoma* cf. *incongrua* associated with *Soletellina minoensis, Saxolucina k-hataii, Cyclina japonica, Ringicula ninohensis,* and *Vicarya callosa japonica.* The association is dominated by deposit feeding species. Although *Anadara daitokudoensis* has not been found, the association is equivalent to the *Anadara-Vicarya* association, and represents the tidal flat community. In front of the tidal flat facies, there are banks of a thick-shelled oyster, *Crassostrea gravitesta.* Oysters are found as clusters in grey muddy sandstone. *Compsomyax iizukai, Panopea kanomatazawaensis,* and *Euspira meisensis* are found among the oysters.

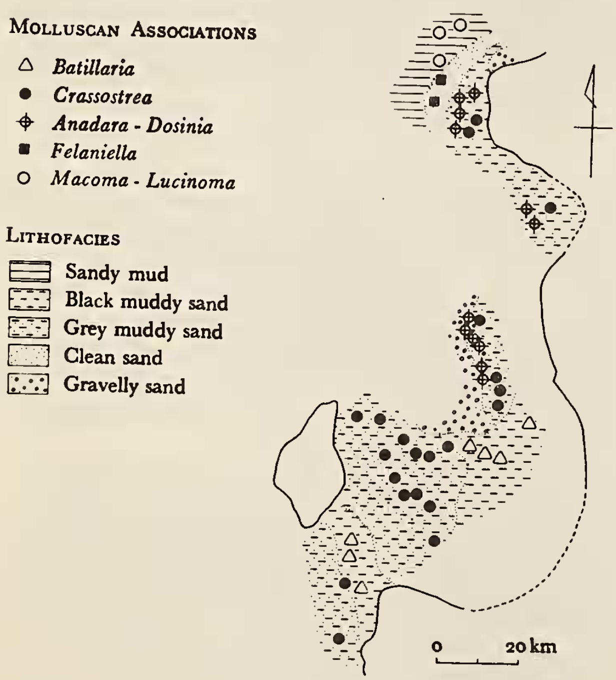


Figure 3

Distribution of the coastal water associations in the basal part of the early middle Miocene Kadonosawa Formation in the Kadonosawa Basin (Locality 17), north of Honshu. Thick line indicates the presumed coastline. Redrawn from Chinzei & Iwasaki (1967)

The main part of the restored bay is occupied by non-stratified, grey muddy fine-grained sandstone. The sandstone contains abundant shallow-burrowing suspension feeding bivalves including *Dosinia nomurai, Clinocardium shinjiense, Anadara ninohensis, Compsomyax iizukai,* and *Tapes siratoriensis.* Other species, such as, *Panopea kanomatazawaensis, Glycymeris cisshuensis,* and *Euspira meisensis,* are also commonly found. Solitary shells of *Crassostrea gravitesta* occur sporadically in the fossiliferous sandstone. This association is considered a sandy bottom community that lived in the central part of the shallow bay. Clusters of *Felaniella usta* occur in well sorted medium-grained sandstone near the bay-mouth. *Felaniella* is associated with *Conus tokunagai, Tapes siratoriensis,* and *Euspira meisensis.*

In sandy mudstone outside of the bay, there is an association composed of *Macoma optiva* with *Lucinoma annulata, Mizuhopecten kimurai,* and *Anadara* sp. This association represents a shallow muddy community in the Kadonosawa Basin.

The fauna has been called the Kadonosawa Fauna (Otuka, 1934), and is considered representative of the Japanese early middle Miocene subtropical faunas. The Kadonosawa type molluscan fauna is known from more than 30 localities in Japan as shown in Figure 2. The fauna in one locality is usually composed of two or three associations corresponding to associations in the Kadonosawa Basin. Mixed occurrences of the species which constitute the different associations in the Kadonosawa Basin are also commonly found. The mixing might have happened in some cases during sedimentation.

The northernmost distribution of elements of the subtropical Kadonosawa Fauna is in the Uryu Coal-Field, central Hokkaido (Loc. 20; Ohara & Kanno, 1973). In this area, sandstone of the lower middle Miocene Shinuryu Formation contains *Anadara ogawai, Dosina nomurai, Tapes siratoriensis,* and *Euspira meisensis;* this association is analogous to the *Anadara-Dosinia* association in the Kadonosawa area. A similar molluscan fauna is known from the Takinoue Formation (Loc. 19) which overlies the Asahi Formation containing the cold water Asahi Fauna. In the Takinoue Formation elements of the *Batillaria* association, *Batillaria yamanarii* and *Macoma incongrua,* etc., have been reported in addition to *Dosinia nomurai, Tapes siratoriensis* and other sandy bottom mollusks

(KANNO & OGAWA, 1961). Mollusks from Tanega-shima (Loc. 8), south of Kyushu, are the southernmost record of the Kadonosawa Fauna (HAYASAKA, 1969). Included are *Anadara daitokudoensis* associated with *Vicarya callosa japonica, Cerithidea shirakii,* and some other potamid gastropods with banks of *Crassostrea gravitesta.*

The Kadonosawa Fauna is known along the Japan Sea coast of the Korean Peninsula. In the Gampo area, southeastern Korea (Loc. 21), the middle Miocene Eoil Formation contains the *Anadara-Vicarya* association identical to the Japanese tidal flat community, as well as beds of *Crassostrea gravitesta* (KIM *et al.,* 1974). The same association was reported from the basal part of the Miocene Meisen Series in the Myonchon (Meisen) area of northern Korea (Loc. 22). Many of the characteristic species of the Kadonosawa Fauna were first described from here by MAKIYAMA (1926, 1936). The upper part of the Series is rich in late Miocene cold water mollusks as discussed later.

A belt of marine sedimentation was formed through western Honshu in an east-west direction during the middle Miocene. This belt of sedimentation is called the Setouchi Province, antecedent of the present-day Setouchi Inland Sea. The marine deposits of the Setouchi Province contain abundant molluscan fossils, especially in the lower part, the transgressive lower middle Miocene. ITOIGAWA & SHIBATA (1973) distinguished 16 associations in the Mizunami and surrounding area, eastern Setouchi Province (Loc. 12), ranging in habitat from intertidal to uppermost bathyal and from gravel-rock to muddy facies. Thirteen of these are shallow water associations. They are basically comparable with those in the Kadonosawa area, but there are some differences in species composition. Among the associations they described, that dominated by *Saccella miensis, Venericardia siogamensis* and *Cultellus izumoensis,* associated with *Macoma optiva* and *Lucinoma acutilineatum,* is typical of the shallow water muddy bottom community. The subtidal muddy bottom association is poorly represented in the Kadonosawa and other areas. In detail, the muddy bottom association is divided into two parts, the *Saccella-Cultellus* and the *Macoma-Lucinoma* associations (ITOIGAWA, 1974). The latter probably lived in deeper water than the *Saccella-Cultellus* association.

Gravel bottom communities are characterized by the abundant occurrence of pectinid species. In the Nanao area (Loc. 14) of the Noto Peninsula, central Honshu, *Nanaochlamys notoensis, Kotorapecten kagamianus, Placopecten akihoensis* occur in loose, pumiceous sandstone (MASUDA, 1962). The association is typical of the subtropical shallow sea pectinid-rich communities; associations of similar composition have been recorded from many places in northeastern Honshu and southern Hokkaido (MASUDA, 1962). Conglomeratic sandstone of the Moniwa Formation near Sendai (Loc. 16) is an example. It yields *Chlamys arakawai, C. cosibensis, Aequipecten yanagawaensis,* in addition to the species known from Nanao. Rocky bottom communities are uncommon among the early middle Miocene faunas. MASUDA (1966) described the rocky bottom mollusks from the tip of the Noto Peninsula (Loc. 15), where *Haliotis notoensis, Turbo ozawai, Nerita ishidae,* and *Cypraea ohiroi* are found in association with fragments of corals, larger foraminifers in the conglomeratic sandstone of the Higashi-Innai Formation.

The cold shallow water molluscan fauna of early middle Miocene is known only in northern Hokkaido. In the Chikubetsu area (Loc. 7), the middle Miocene Chikubetsu Sandstone contains *Spisula onnechiuria, Peronidia t-matsumotoi, Mercenaria chitaniana, Mya cuneiformis, Tectonatica ezoana, Neptunea oomurai* and some other mollusks (KANNO & MATSUNO, 1960). The mollusks are shallow water inhabitants judging by the generic composition and lithologic characters of the enclosing sediments. However, there are no species in common with the Kadonosawa type sandy associations, and the Chikubetsu Fauna is thus considered to be the cold water counterpart of the subtropical sandy bottom communities. The same cold water association was reported from the lower part of the Shinuryu Formation in the Uryu area (Loc. 20). It is worthy of note that in the Shinuryu Formation, the Kadonosawa type *Anadara-Dosinia* association is found from the horizon slightly lower than that of the Chikubetsu Fauna (OHARA & KANNO, 1973). This indicates the contemporaneity of the Kadonosawa and the Chikubetsu Faunas.

The occurrence of the offshore molluscan fauna is sporadic when compared with the shallow coastal water associations. The lower middle Miocene nearshore sediments in the Setouchi Province are succeeded by offshore type mudstone containing planktic foraminifera and other oceanic planktons of southern aspect. The mudstone is poor in benthic mollusks. Locally nuculanid bivalves, *Portlandia tokunagai, P. watasei, Malletia inermis, Yoldia sagittaria,* are found in association with *Periploma besshoensis, Lucinoma acutilineatum, Akebiconcha chitanii* and some other bivalves (e.g., Loc. 11, SHIKAMA & KASE, 1976; Loc. 12, ITOIGAWA, 1960). The muddy fauna characterized by *P. tokunagai* and *M. inermis* is found in several other areas of north-central Honshu and Hokkaido. The species composition is strikingly uniform throughout these areas. The same association is also found in the early Miocene deposits and the Asahi and the Sankebetsu Formations in central Hokkaido as noted before. The bathymetric relationship between the *Portlandia* association and the subtropical Kadonosawa Fauna is assumed to be the same as that seen in the early Miocene faunas. The cold water type *Portlandia* association extended its distribution southward into deep water, transported possibly by the previously mentioned cold water undercurrent. Vertical stratification of warm and cold water masses in the Mizunami area (Loc. 12) is proved by the fact that the warm water nautiloid, *Aturia minoensis,* is preserved in association with cold water benthic mollusks.

In early middle Miocene time, the convergence of warm and cold currents was presumably located in central Hokkaido as indicated by the distribution of two shallow water molluscan faunas. The location is about 8° N of the present-day convergence of the warm Kuroshio and cold Oyashio Currents, which is at about 36° N latitude with seasonal fluctuations, along the Pacific coast of Japan. On the other hand, the middle Miocene undercurrent of cold water probably reached down to central Honshu, about 35° N, as suggested by the distribution of the *P. tokunagai* association, the position approximately the same as today. OKUTANI (1972) noted the reduction of size among the subarctic mollusks which are living in the Oyashio Undercurrent in Sagami Bay, central Honshu. No such phenomenon has been reported for the Miocene deep water species.

MIDDLE MIOCENE FAUNA

Middle Miocene deposits in the Japanese Islands are predominated by offshore mudstone. They are represented by hard diatomaceous shale in the Japan Sea coast areas where the shale has been called the Onnagawa Formation and other local names. The diatomite is thought to have been accumulated in silled and stagnant basins (INGLE & GARRISON, 1976).

Shallow water sediments positively able to be correlated with the middle Miocene mudstone and shale facies are not known. Most of the Japanese Islands are likely to have been submerged in deep quiet waters. The shale as well as clastic mudstone is extremely poor in benthic megafossils. Scattered mollusks including *Portlandia tokunagai, Conchochele disjuncta, Lucinoma acutilineatum,* and some other bivalves have been reported from the mudstone. The molluscan fauna of this age is very poorly understood.

LATE MIOCENE FAUNAS

The shallow water sediments reappeared in the late Miocene along the marginal parts of the basins and surrounding the newly emerged lands in Northeast Japan and the Japan Sea coast areas. The sediments are rich in molluscan fossils. In the depocenter of the basin, the middle Miocene shale and mudstone is succeeded by grey siltstone or fine-grained sandstone containing offshore type mollusks. The age of reappearance differs from place to place; the earliest may have been in the middle Miocene, around 12 my ago.

Apparently tropical and subtropical mollusks, which predominated during the early middle Miocene disappeared from Northeast Japan and the Japan Sea coast prior to the late Miocene. The subtropical fauna was restricted to the Pacific coast of Southwest Japan (Figure 4).

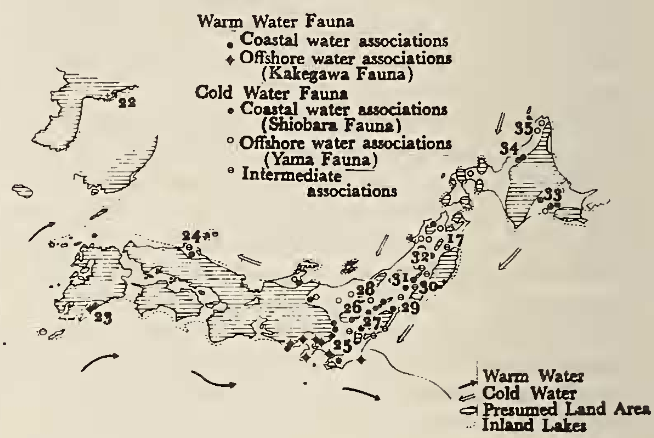


Figure 4

Distribution of the late Miocene molluscan faunas and presumed paleogeography of Japan during the late Miocene. Numerals indicate the fossil localities mentioned in the text: 23: Miyazaki; 24: Fujina in Sanin District; 25: Zushi in the Miura Peninsula; 26: Shiobara 27: Tanagura; 28: Yama in the Aizu District; 29: Nanakita, north of Sendai; 30: Ichinoseki; 31: Kurikoma; 32: Kurosawa; 33: Atsunai; 34: Togeshita; 35: Wakkanai

The late Miocene subtropical fauna is typically seen in the Miyazaki area (Loc. 23), southern Kyushu. Muddy sandstone of the lower Miyazaki Group contains *Paphia exilis, Amussiopecten iitomiensis, Crassatellites tenuiliratus,* associated with *Joannisiella cummingi, Dosinia* spp., *Cardium* spp., *Clementia* and other bivalves and gastropod species (SHUTO, 1961). The fauna is comparable in generic composition to the Recent inner sublittoral sandy communities of an open coast. The association of outer sublittoral character is found in sandy siltstone of the lower to middle part of the Miyazaki Group. It consists of *Acila submirabilis, Limopsis obliqua, Glycymeris rotunda, Nemocardium samarangae, Ancilla otukai, Polinices reiniana,* and some other minority species. No intertidal community is known in the fauna.

The fauna has a close similarity to the Plio-Pleistocene Kakegawa Fauna, which will be discussed later, both in species composition and in distribution. Late Miocene and Plio-Pleistocene faunas both lived in coastal and offshore waters probably affected as today by the warm Kuroshio Current. The differences between them may be attributed simply to their differing geologic ages. They are both called the Kakegawa Fauna in this paper.

In southern Kanto, there is a peculiar assemblage composed of shallow water rocky or gravelly bottom species mixed with offshore deep water forms. The basal conglomerate of the Kazusa Group in the Miura Peninsula (Loc. 25) contains *Chlamys miurensis, Amussiopecten iitomiensis, Glycymeris cisshuensis, Turbo* sp., *Haliotis* sp., associated with *Phanerolepida transenna, Mikadotrochus yoshiwarai, Halicardia* sp., and other deep water species (SHIKAMA, 1973). Analogous mixed assemblages are found in several localities of the same horizon in Kanto.

Two late Miocene cold water faunas, the nearshore Shiobara Fauna and the offshore Yama Fauna, have been recognized in Northeast Japan and along the Japan Sea coast (CHINZEI, 1963).

The species characteristic of the Shiobara Fauna were first reported from the Shiobara area, central Honshu (Loc. 26) by YOKOYAMA (1926). Composition of the fauna and its relation to habitats in the Tanakura and Shiobara areas were described by IWASAKI (1970). An embayment of late Miocene age has been restored in the Tanakura area (Loc. 27). The horizontal distribution pattern of mollusks in the restored bay is similar to that in the early middle Miocene Kadonosawa Basin. In front of the fresh water sand and lignite areas of the bayhead, there is a belt of banks and colonies of *Crassostrea gigas* with some other species. This represents the tidal flat community. Inside the belt of oyster banks, an area of the *Anadara-Dosinia* association occurs. The association is characterized by high diversity of species and large numbers of individuals. It is dominated by *Anadara ninohensis,* in association with *Dosinia kaneharai, Felaniella usta, Laevicardium shiobarense, Glycymeris cisshuensis, Protothaca tateiwai,* other shallow-burrowing bivalves, and with the gastropods *Neverita kiritaniana* and *Phos iwakianus.* The association is equivalent to the *Anadara-Dosinia* association in the Kadonosawa Basin. The main part of the bay is occupied by massive fine-grained sandstone, in which *Lucinoma annulata, Macoma optiva, Turritella tanaguraensis* are found. This is comparable with the early middle Miocene *Lucinoma-Macoma* association of subtidal muddy bottom. There are small lenses of pumiceous coarse-grained sandstone in the massive sandstone area. The lenses contain a pectinid association consisting of *Mizuhopecten paraplebejus, Miyagipecten matsumoriensis, Chlamys kaneharai,* with *Glycymeris yessoensis* and a few other species.

The occurrence of *Dosinia kaneharai, Laevicardium shiobarense,* and *Chlamys kaneharai* is a characteristic feature of the Shiobara Fauna. The fauna has been reported from the northern margin of the Kanto Basin, and extends farther along the row of islands which was emergent during middle and late Miocene at the position now occupied by the Ou Range. In the Kurikoma area (Loc. 31), central Ou Range, the fauna is characterized by *Spisula kurikoma,* a species common in northern Honshu and Hokkaido, in addition to *Dosinia kaneharai* and *Laevicardium shiobarense.* The same fauna has been called the Togeshita Fauna in Hokkaido, and is known from several areas, e.g., Togeshita (Loc. 34), Atsunai (Loc. 33), in central and eastern Hokkaido (UOZUMI, 1962). In the Sanin district (Loc. 24), western Honshu, the Upper Miocene Fujina Formation, consisting of fine-grained sandstone, contains *Anadara ogawai, Dosinia kaneharai, Mercenaria yokoyamai, Cultellus izumoensis,* and others accompanied by *Nautilus izumoensis.* The fauna, characterized by occurrence of *Anadara ogawai, Laevicardium shiobarense, Dosinia kaneharai* and other species of the Shiobara Fauna, is known from the upper part of the Miocene Meisen Series in northern Korea (Loc. 22; MAKIYAMA, 1936).

The shallow water type Shiobara Fauna is composed of *Anadara, Dosinia,* and other genera derived from the Indo-Pacific region intermingled with such northern species as *Glycymeris yessoensis* and *Spisula kurikoma,* etc. Since there are no apparent warm water species in the fauna, the Shiobara most probably lived in cold water, presumably coastal water in the temperate region. The Indo-Pacific elements may be considered as the descendants of invaders from the south in the early middle Miocene, who remained in the coastal area after the retreat of the warm current and succeeded in adapting themselves to cold water.

The offshore type Yama Fauna was first described by NOMURA (1935) from the Aizu area (Loc. 28). OTUKA (1941) noticed its offshore nature based on an association from the Kurosawa area (Loc. 32). In Hokkaido, the fauna of the same composition is called the Wakkanai Fauna (UOZUMI, 1962). The Yama Fauna is characterized by buccinid and neptuneid gastropods, such as *Ancistrolepis mogamiensis, Buccinum ishidai, Neptunea nomurai,* and by the cardiid bivalves *Serripes groenlandicus* and *S. yokoyamai,* associated with *Conchocele bisecta* and other bivalves. Analogous associations of species are living in subarctic water in outer sublittoral to upper bathyal zones. Characteristic species of the Yama Fauna are found solitarily or a few species together in grey siltstone accumulated in the basins west of the row of newly emerged islands. In Hokkaido, it is known from the Wakkanai Shale (Loc. 35) and its equivalents, in which the species of the Yama Fauna are associated with *Portlandia watasei, P. thraciaeformis* and others.

The association intermediate in character between the offshore type Yama Fauna and the nearshore Shiobara Fauna is frequently found in fine-grained sandstone distributed between the shallow water sand facies and the deep water mud facies. The fossiliferous Kurosawa Formation in the Kurosawa area (Loc. 32) becomes sandy eastward, closer to an inferred island, where it contains *Macoma optiva, Lucinoma acutilineatum, Panomya simotomensis,* and *Cultellus izumoensis,* with *Serripes* spp. and a few gastropods (HAYASAKA, 1957). Similar fine-grained sand associations are dominant in the basins east of the row of islands, e.g., Ichinoseki (Loc. 30), Nanakita (Loc. 29), and Kadonosawa areas (Loc. 17). *Miyagipecten matsumoriensis* is another characteristic species of this fine-grained sandstone facies. Conglomeratic sandstone of the same horizon yields a pectinid association characterized by *Mizuhopecten kimurai, Kotorapecten yamasakii,* and *K. tryblium* (e.g. Loc. 17, MASUDA, 1962).

PLIOCENE AND EARLY PLEISTOCENE FAUNAS

Structural growth of the Japanese Islands became pronounced during the Pliocene and early Pleistocene, during which time the areas of marine sedimentation were reduced to the coastal belts of the Pacific and Japan Sea. A minor transgression is recognized, however, in Northeast Japan in the late Pliocene. It formed deep embayments in the Pacific side of northern Honshu and central and north Hokkaido. Faunal characters and their distribution during the Pliocene and early Pleistocene were not markedly different from the preceding late Miocene, although some constituent species were replaced by new forms (Figure 5).

A warm water fauna of Pliocene and early Pleistocene age, the Kakegawa Fauna, is distributed along the Pacific coast of Southwest Japan. This fauna comprises associations of diverse habitats, from inner sublittoral to bathyal zones. The fauna is comparable to the living fauna in central and western Japan in the waters associated with the Kuroshio Current. A typical set of the associations is observed in the Kakegawa Group in the Pacific coast of central Honshu (Loc. 37). The Kakegawa area has been studied repeatedly, and faunal characters are best understood here among the distribution areas of the Kakegawa Fauna (e.g., MAKIYAMA, 1931; TSUCHI, 1960).

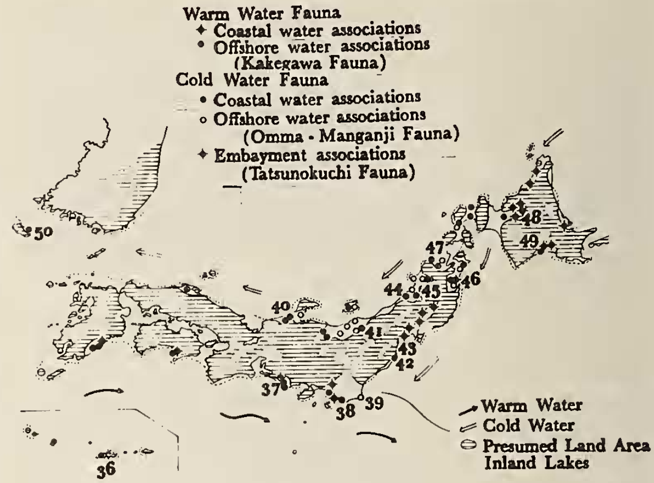


Figure 5

Distribution of the Pliocene and early Pleistocene molluscan faunas and presumed paleogeography of Japan during the Pliocene and early Pleistocene. Numerals indicate the fossil localities mentioned in the text; 36: Shimajiri in Okinawa-jima; 37: Kagegawa; 38: Kurotaki in the Boso Peninsula; 39: Choshi; 40: Omma in Kanazawa; 41: Higashiyama; 42: Futaba; 43: Sendai; 44: Manganji; 45: Futatsui; 46: Sannohe; 47: Tsugaru; 48: Takikawa; 49: Honbetsu; 50: Cheju Island

An inner sublittoral coastal water association is known in the marginal and basal medium-grained sandstone facies of the Kakegawa Group. It is composed mainly of sandy bottom dwellers intermingled with the species from other habitats. The association is characterized by the common occurrence of *Anadara castellata, Venericardia panda, Amussiopecten praesignis, Glycymeris nakamurai, Turritella perterebra,* and *Umbonium suchiense.* The species are peculiar to the Kakegawa Fauna, and the occurrence of one of these species is thought to be indicative of the distribution of the fauna.

Lateral change of offshore molluscan fauna corresponding to the lithofacies changes in the Kakegawa Group have been noted by CHINZEI & AOSHIMA (1976). In the offshore area of medium-grained sand, there is a belt of fine-grained muddy sandstone containing outer sublittoral muddy bottom mollusks such as *Venus foveolata, Glycymeris rotunda, Nemocardium samarangae,* and *Siphonalia spadicea.* The association from the coarse-grained siltstone is dominated by gastropod species, now living in the uppermost bathyal zone, such as *Nassaria magnifica, Makiyamaia coreanica, Fulgoraria hirasei,* and *Lunatia plicispira.* The offshore fine-grained siltstone contains scattered *Limopsis tajimae,* a species characteristic of the present-day upper bathyal, associated with *Neilonella coix, Malletia inaequilateralis,* and gastropods in common with the coarse-grained siltstone facies.

Associations similar to those in the Kakegawa area are distributed along the Pacific coast of Southwest Japan southward to the Ryukyu Islands. The coastal water associations have not been found on Okinawa-jima and other nearby islands (MacNeil, 1960). A bathyal molluscan fauna, representing the deepest association among the known Kakegawa Fauna, is reported from Okinawa-jima (Loc. 36, Noda, 1976). It includes *Neilonella japonica, Bathyarca sibogai, Turricula aeola,* and *Benthovoluta hilgendorfi*. The northeastern limit of distribution of the shallow water association is found in the central part of the Boso Peninsula, southern Kanto (Loc. 38).

The Pliocene and Early Pleistocene molluscan fauna of the Japan Sea coast of Honshu has been called the Omma-Manganji Fauna. The general character of the fauna is cold water, composed of species now living in the areas under the influence of the cold Oyashio Current, and by extinct species. Three principal associations are recognized in the Omma-Manganji Fauna: coastal water sandy bottom associations, coastal water gravelly bottom associations, and offshore muddy bottom associations.

The typical composition of the shallow sandy bottom associations was described in the Futatsui area, northern Honshu (Loc. 45, Chinzei, 1973), where two types of associations are recognized in fine-grained sandstone. The association from the lower horizon is characterized by the predominance of *Limopsis tokaiensis, Acila nakazimai, Venericardia ferruginea,* and *Turritella saishuensis*. The association presumably lived in deeper water than the overlying *Anadara-Mercenaria* association, as it is found in an intermediate horizon between the offshore muddy association and the *Anadara-Mercenaria* association. The *Anadara-Mercenaria* association, found in the upper horizon, is composed mainly of *Turritella saishuensis, Macoma tokyoensis, Anadara amicula, Mercenaria stimpsoni, Dosinia japonica, Mya cuneiformis, Thracia kakumana,* and *Felaniella usta*.

The fauna in gravel or coarse-grained sandstone is characterized by the common occurrence of *Astarte borealis, Glycymeris yessoensis, Chlamys cosibensis, Epitonium* spp., *Ocenebra* spp., and *Boreotrophon* spp., e.g., in the Manganji area (Loc. 44, Otuka, 1936) and in the Nishi-Tsugaru area (Loc. 47, Iwai, 1965). It is usually intermingled with the species probably derived from other facies.

These associations are found separately, or intermingled with each other, in Pliocene and lower Pleistocene sandy sediments in many other areas along the Japan Sea coast. In the Omma area near Kanazawa (Loc. 40), one of the typical localities of the fauna, fossils are found as shell beds composed mainly of the species in common with, or closely related to, those in the Futatsui area. They are intermixed with those from other facies (Ogasawara, 1977). There are some indigenous species such as *Mizuhopecten tokyoensis hokurikuensis, Anadara ommaensis,* and *Pseudamiantis tauyensis*.

The offshore muddy fauna in the Futatsui area is represented by *Nuculana robai, Macoma calcarea, Serripes groenlandica, Conchocele bisecta, Turritella nipponica, Buccinum tsubai,* and *Rectiplanes sadoensis* (Chinzei, 1973). These species are found sporadically in grey siltstone. In general, the offshore muddy association in the Omma-Manganji Fauna is characterized by the dominance of gastropods such as *Admete, Antiplanes, Propebela,* and other buccinid and turrid species.

As the Pliocene and the lower Pleistocene strata on the Japan Sea coast areas were accumulated at the last stage of reclamation of the Neogene basins, the offshore fauna tends to occur in the lower horizon, and is replaced upward by the shallow water associations as observed in the Futatsui area. The age of appearance of the shallow water association may differ in places, it is earlier in the marginal areas and later in the central parts of the basin.

The westernmost distribution of the Omma-Manganji Fauna is on Cheju (Saishu) Island (Loc. 50), southern Korea, from which *Turritella saishuensis* was described by Yokoyama (1923). In this locality, *T. saishuensis* is associated with *Venericardia ferruginea, Chlamys cosibensis, Mizuhopecten tokyoensis,* and some other mollusks. No further information is available on the fauna associated with *T. saishuensis* on Cheju Island. The distribution of the Omma-Manganji Fauna is thought to be confined to the Japan Sea coast area. However, shallow sandy mollusks from the Futaba area (Loc. 42), south of Sendai, may be referred to the Omma-Manganji Fauna (Hayasaka, 1956). Also, an offshore muddy association similar to that in the Omma-Manganji Fauna is recorded in the Choshi area (Loc. 39), eastern Kanto (Ozaki, 1958).

It should be noted that the elements of the warm Kakegawa Fauna, *Glycymeris nakamurai* and *Umbonium suchiense,* were reported in association with the Omma-Manganjian shallow water sandy mollusks from the Higashiyama area, Niigata Oil Field (Loc. 41, Kanehara, 1940). Occurrence of the warm water Kakegawa elements on the Japan Sea coast of central Honshu indicate a marine connection with the Pacific side.

The embayments formed during the minor late Pliocene transgression were inhabited by a fauna of brackish and shallow marine aspect. The fauna, called the Tatsunokuchi (Tatunokuti) Fauna, is characterized by bivalve species indigenous to these embayments, particularly by a hump-backed pectinid, *Fortipecten*. It is typically found in the Sendai Basin (Locs. 30 and 43), and is known from the Sannohe area in northern Honshu (Loc. 46), and the Takikawa (Loc. 48), Honbetsu (Loc. 49) and other areas in northern and eastern Hokkaido. In the Sendai basin, *Fortipecten takahashii* is found in poorly sorted medium- to coarse-grained sandstone in association with *Pseudamiantis sendaicus, Anadara tatunokutiensis, Dosinia tatunokutiensis, Peronidia* sp., *Neverita kiritaniana*, and other species. Although the association represents the Tatsunokuchi Fauna, it is found in restricted parts of the restored bay (Chinzei & Iwasaki, 1967). The inner half of the deep embayment is an area of dark grey sandy siltstone, in which large banks of *Crassostrea gigas* are predominant; the central part of the bay is occupied by a *Macoma-Mya* association composed of *Macoma tokyoensis, Mya japonica*, and *Lucinoma annulata*, found sporadically in grey massive siltstone (Figure 6).

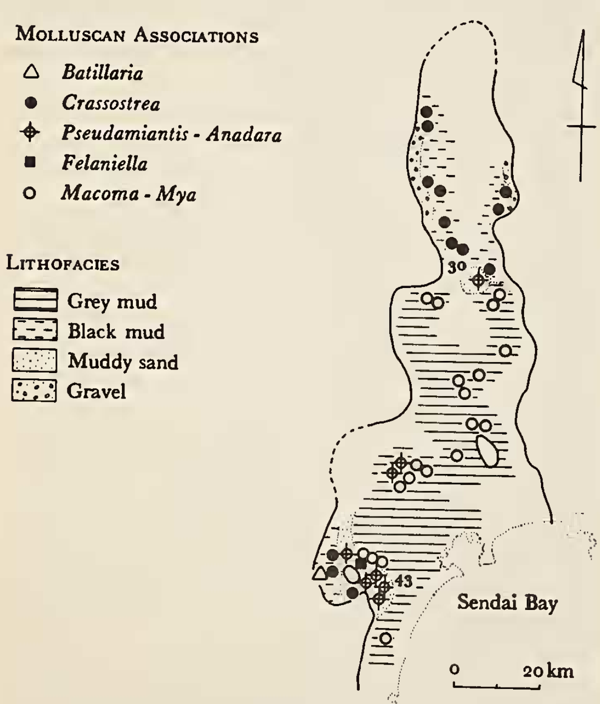


Figure 6

Distribution of the coastal water associations in the late Pliocene embayment of the Sendai Basin. Thick line indicates the presumed coastline. Locality 30: Ichinoseki; Locality 43: Sendai. Redrawn from Chinzei & Iwasaki (1967)

The shallow water association in the Sannohe area (Loc. 46) is peculiar in the combined occurrence of the Tatsunokuchian and Omma - Manganjian species (Chinzei, 1961). The association from poorly sorted medium-grained sandstone is characterized by *Anadara tatunokutiensis, Peronidia protovenulosa, Mercenaria stimpsoni, Spisula kurikoma*, and *Fortipecten kenyoshiensis*. An offshore muddy association of the Omma-Manganji type is found in the central and deeper part of the Sannohe Basin. *Fortipecten takahashii* is associated with *Turritella fortilirata, Spisula voyi, Macoma tokyoensis, Yoldia macroshema, Anadara "trilineata",* and *Mya japonica* in the Takikawa area (Loc. 48), central Hokkaido. The fauna is found in the innermost part of the embayment. The association characterized by *Fortipecten takahashii* is commonly found in the Plio-Pleistocene sandy facies of northern and eastern Hokkaido.

The shallow sandy association of *Fortipecten takahashii* is dominated by *Anadara, Dosinia, Peronidia*, and *Pseudamiantis* or *Mercenaria* in the Sendai and other areas. The principal generic composition is comparable to that of the shallow sandy association of the Omma-Manganji Fauna in Futatsui and other areas, although there are no species in common. The *Anadara-Dosinia* association of the Tatsunokuchi and the Omma-Manganji faunas occupied a similar biotope in the different basins, but they are thought to have been separated zoogeographically from each other.

PALEOECOLOGICAL NOTES ON THE JAPANESE NEOGENE MOLLUSCAN FAUNAS

Most associations represent original species associations. This is confirmed by observations of autochthonous fossil occurrences, i.e., individuals that lived together and were buried at their living places. Some other associations do not show positive evidence of *in situ* preservation, but identical species associations have been reported from many localities. Their compositional identity suggests that the observed species composition is original. Such an association represents part of the original benthic community in the sense of Petersen (1913).

Similarity of species composition is remarkable among the shallow water associations of different ages, especially among those of the embayments (Figure 7). Associations characterized by potamid gastropods and oysters of the genus *Crassostrea* are known from all 4 faunas of different

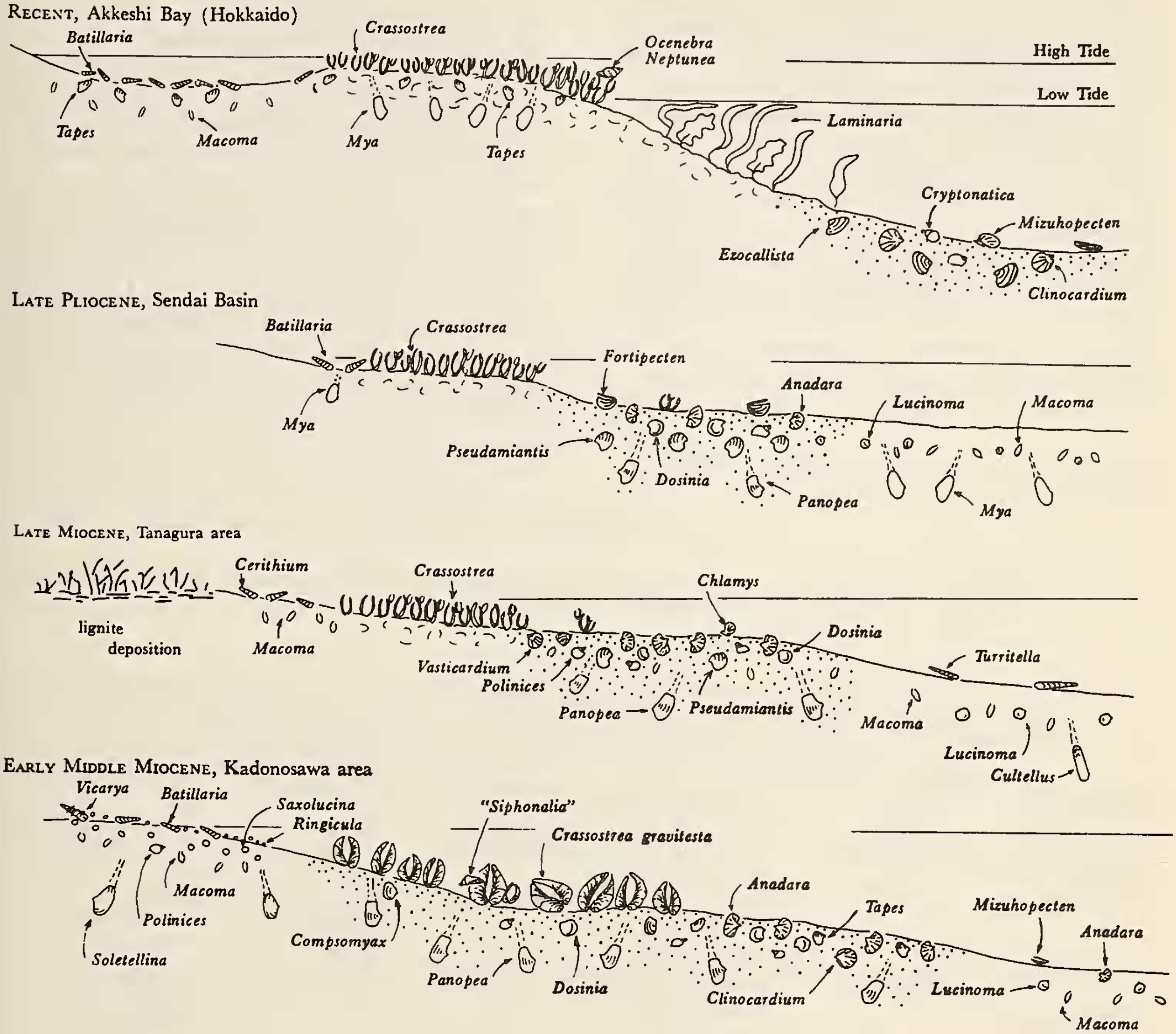


Figure 7

Coastal water molluscan associations of the early middle Miocene Kadonosawa Fauna (Kadonosawa Basin, Locality 17), the late Miocene Shiobara Fauna (Tanagura area, Locality 27), and the Pliocene Tatsunokuchi Fauna (Sendai Basin, Locality 43). Recent cold water associations in Akkeshi Bay and adjoining brackish water Akkeshi Lake, eastern Hokkaido, are also shown for comparison.

ages. They are found invariably in mud or muddy sand of the marginal part of a sedimentary basin or the innermost part of an embayment. They may represent intertidal communities. Shallow water sandy facies were populated by associations dominated by *Dosinia, Anadara, Cardium* and other shallow-burrowing suspension feeders. They are commonly associated with carnivorous naticid gastropods. The species diversity as well as population density in this facies are the highest of all of the Neogene molluscan associations. The high proportion of burrowing suspension feeders corresponds with that of the present-day sandy bottom fauna (Sanders, 1958; Kikuchi, 1977). The shallow muddy bottom associations are dominated by *Macoma* and

Lucinoma in common besides other species peculiar to each association. They are rich in deposit feeding forms. Naticids are uncommon in these associations. Table 1 shows a comparison of the principal constituents of representative shallow water and embayment associations.

These similarities of composition are indicative of analogous ecologic characters of the associations. The ecologically congruent relationships of the associations were first discussed by Chinzei & Iwasaki (1967) for the shallow sea faunas in northern Honshu. They called the relationship chronologically parallel comparing it with geographically parallel ones seen in the Recent benthic communities (Thorson, 1957). Congruent relationships are not clear among the offshore associations in the Japanese Neogene.

Species are usually replaced, between the congruent associations of different ages, by different species belonging to the same genus or ecologically allied genera. The replacement of species may be the consequence of evolutionary change within the same genus, as well as new immigration from the south to the north. For example, species of *Anadara* that lived in Northeast Japan from the late Miocene through the early Pleistocene are probably the descendants of species that invaded Japanese waters from the south during early middle Miocene time. The species found in the Kakegawa Fauna, however, is considered to be an immigrant from the south during Pliocene. The coastal water mollusks living in present-day Japanese waters may be the descendants of species that lived in coastal waters during Neogene and partly species that immigrated from the south during the late Pleistocene and post-glacial ages.

Table 1

Species composition of representative coastal water associations in the Neogene molluscan faunas in Japan. Note the occurrence of the same or ecologically allied species among the associations of different ages.

Age (Example) Presumed Environment	Early Miocene (Loc. 2, Kottoi; subtropical)	Early Middle Miocene (Loc. 17, Kadonosawa; subtropical) *(Loc. 12, Mizunami)	Late Miocene (Loc. 27, Tanagura; temperate)	Pliocene—Early Pleistocene (Loc. 43, Sendai; temperate)	Living (Akkeshi, Hokkaido; cold temperate)
Tidal flat (muddy sand or sandy mud facies)	*Batillaria takeharai*	*Batillaria yamanarii* *Vicarya callosa japonica* *Macoma cf. incongrua* *Soletellina minoensis* *Cyclina japonica*	*Cerithium kobelti* *Macoma incongrua*	*Batillaria multiformis* *Macoma incongrua* *Mya japonica*	*Batillaria cumingi* *Macoma incongrua* *Mya japonica* *Tapes japonica*
Intertidal (muddy or sandy facies)	*Crassostrea* sp.	*Crassostrea gravitesta* *Compsomyax iizukai* *Panopea kanomatazawaensis*	*Crassostrea gigas*	*Crassostrea gigas*	*Crassostrea gigas* *Tapes japonica* *Mya japonica*
Level bottom (sandy facies)	*Dosinia chikuzenensis* *Glycymeris cisshuensis* *Pitar matsumotoi* *Sollen connectens* *Solen connectens*	*Dosinia nomurai* *Glycymeris cisshuensis* *Tapes siratoriensis* *Compsomyax iizukai* *Anadara ninohensis* *Clinocardium shinjiense* *Panopea kanomatazawaensis* *Euspira meisensis*	*Dosinia kaneharai* *D. japonica* *Glycymeris cisshuensis* *Protothaca tateiwai* *Pseudamiantis pinguis* *Mercenaria yokyamai* *Anadara ninohensis* *Laevicardium shiobarense* *Panopea japonica* *Neverita kiritaniana*	*Disinia tatunokutiensis* *Glycymeris gorokuensis* *Pseudamiantis sendaicus* *Anadara tatunokutiensis* *Clinocardium pseudofastosum* *Panopea japonica* *Neverita kiritaniana*	*Glycymeris yessoensis* *Ezocallista brevisiphonata* *Clinocardium californiense* *Cryptonatica janthostoma*
Level bottom (muddy facies)	*Angulus maximus* *Venericardia subnipponica* *Cultellus izumoensis*	**Macoma optiva* *Venericardia siogamensis* *Lucinoma acutilineatum* *Cultellus izumoensis*	*Macoma optiva* *Lucinoma annulatum* *Cultellus izumoensis*	*Macoma tokyoensis* *Lucinoma annulatum*	

SUMMARY OF ZOOGEOGRAPHIC CHANGES OF THE JAPANESE ISLANDS DURING NEOGENE AS VIEWED FROM BENTHIC MOLLUSKS

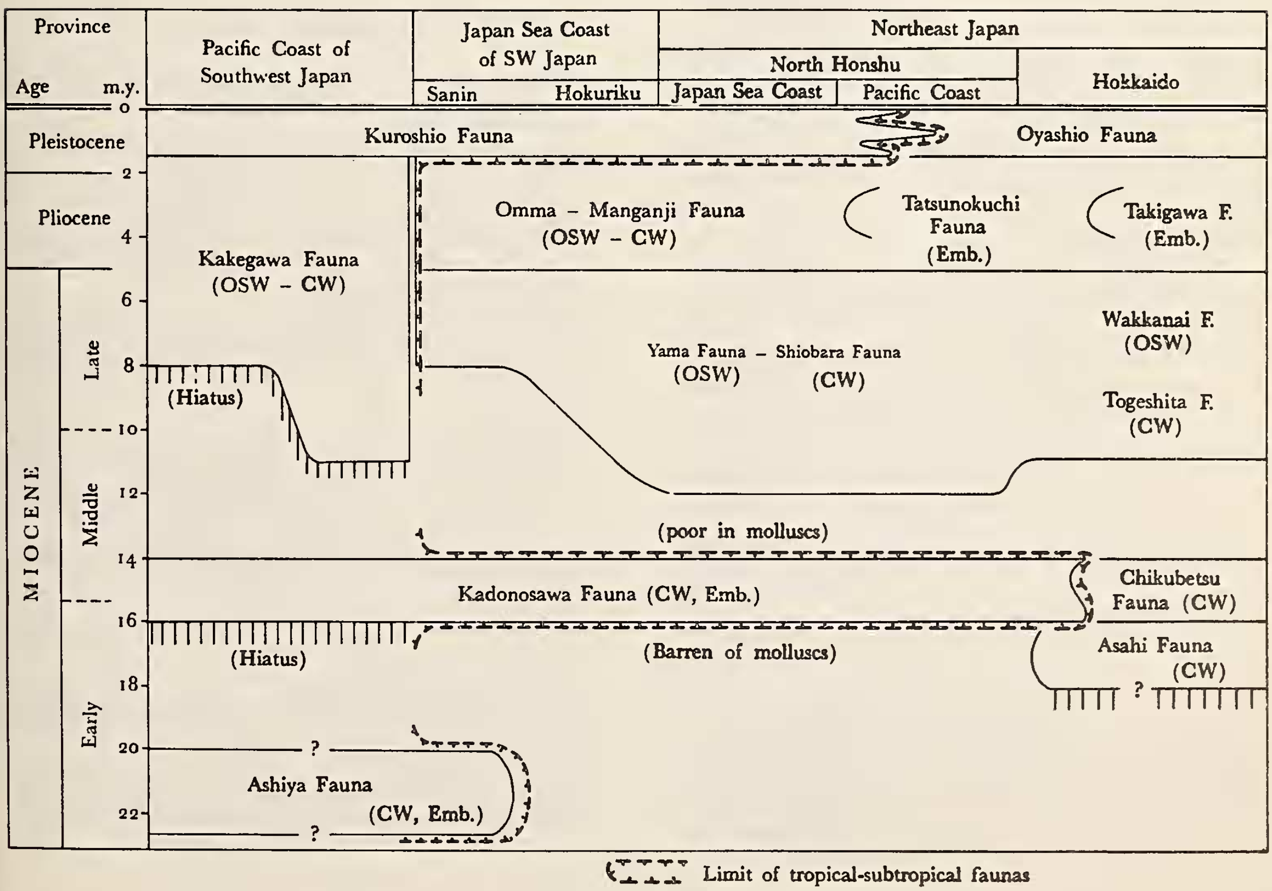
Distributions of the Neogene molluscan faunas in space and time are summarized in Figure 8. The boundaries of the faunas are greatly simplified, and the chronologic positions of the early Miocene faunas are tentative.

The predominance of warm water faunas in early middle Miocene time is the most pronounced event in the faunal history of the Japanese Neogene mollusks. At this time the convergence between warm and cold currents, the subtropical front, was most probably located as far north as central Hokkaido. A major part of Japan was inhabited by the tropical and subtropical coastal water faunas. The main stream of the warm water current probably passed along the Japan Sea side of the Islands, because the tropical mollusks are known only from the Japan Sea coast and adjoining areas in western Japan. The vertical structure of water masses in the early middle Miocene was possibly different from that of present-day Japanese waters. The undercurrent of cold water reached down to central Honshu along the Pacific coast, approximately at the same position as today. Perhaps the early middle Miocene warm surface current in the area now constituting Japan was thinner than the present Kuroshio Current, thus allowing a deep, cold water tongue to advance far south of and beneath the subtropical front.

Figure 8

(below)

Chronologic and geographic distributions of the Japanese Neogene and Pleistocene molluscan faunas. osw: offshore water associations; cw: coastal water associations; emb: embayment and brackish water associations.



Duration of pronounced warming was probably short, around 1 or 2 my, apparently within Blow's planktic foraminiferal Zones N8 and N9. The beginning of the warm period is uncertain. It might have been contemporaneous with the start of the middle Miocene transgression. Data are too scanty to obtain a clear image of zoogeography during the early Miocene, and the transition from the early Miocene faunas to those of early middle Miocene is obscure.

The early middle Miocene period of warming has been recorded from the northern and eastern coast of the Pacific (e.g., ALLISON, 1976; ADDICOTT, 1969), as well as from the South Pacific (HORNIBROOK, 1977) and from the Antarctic Sea (SHACKLETON & KENNETT, 1975). This indicates that the faunal episode in Japan was induced by global activation of warm current systems.

The end of the warm period is seemingly abrupt as far as the benthic faunas are concerned. In the late Miocene no apparent subtropical species has been reported from the entire Japan Sea coast area. The late Miocene faunas in the Japan Sea areas are composed exclusively of the cold water species, elements of the subarctic and coastal waters of the temperate region. This is a sharp contrast to the tropical or subtropical nature of the early middle Miocene faunas in these areas. The switchover from warm to cold water happened during the middle Miocene, around 14 my ago, as revealed by an abrupt change of benthic foraminiferal fauna in the Japan Sea areas (e.g., TAI, 1963; MAIYA, 1977). TAI (1963: 4) called the horizon of change as "Foram. Sharp Line." The sharp change in the Japan Sea area might be the result of closure of the Korean Strait, rather than abrupt global change of climate.

The benthic molluscan faunas in the Japan Sea areas have maintained their cold water nature from the late Miocene through the beginning of the early Pleistocene. Apparent warm water species reappeared in the Japan Sea areas during the early Pleistocene and later as exemplified by the occurrence of *Conus* and other warm water species from the upper part of the Omma Formation (OGASAWARA, 1977). KOIZUMI (1977) noted the occurrence of a warm water diatom flora in the late Miocene from a piston-core sample obtained in the central part of the Japan Sea. He considered that the Sea was connected with the Pacific both to the south and to the north. The only indication of this warming found on land is the occurrence of *Nautilus izumoensis* in the upper Miocene of the Sanin area (LOC. 24) and a few other localities.

The convergence of cold and warm waters in the late Miocene was probably located in Kanto, central Honshu, at approximately the same position as today. After this, no marked shift of the position of convergence is detected through the molluscan faunal sequence. The convergence has remained relatively stationary during the late Neogene and the early Pleistocene. Oxygen paleotemperature analysis shows that the thermal structure of the warm water in Plio-Pleistocene time was comparable to that of the present-day Kuroshio and associated water (CHINZEI & AOSHIMA, 1976).

ACKNOWLEDGMENTS

Professor Tetsuro Hanai and my colleagues in the University of Tokyo, and Dr. Yasuhide Iwasaki of Kumamoto University gave valuable suggestions and advice on various aspects of paleontologic problems. Comments on the biogeography and ecology of present Japanese waters were made mainly by Professor Masuoki Horikoshi of the University of Tokyo. Discussions with many other friends were also stimulating for me. The manuscript was reviewed by Dr. Warren O. Addicott of U. S. Geological Survey, Menlo Park, Professor T. Hanai, and Dr. J. A. Grant-Mackie of the University of Auckland, New Zealand. My deep appreciation is due to these persons for their kind help.

Literature Cited

[J: in Japanese; J, E: in Japanese with English abstract]

ADDICOTT, WARREN OLIVER
1969. Tertiary climatic change in the marginal northeastern Pacific Ocean. Science 165: 583-586; 3 text figs.

ALLISON, RICHARD CASE
1976. Late Oligocene through Pleistocene molluscan faunas in the Gulf of Alaska region. Abstr. Pap., First Internat. Congr. Pacif. Neogene Stratigraphy. Tokyo, Japan, May 16-21, 1976: 10-13. Repr. Proc. First Internat. Congr. Pacif. Neog. Stratigraphy 313-316; 1 text fig., 1 table. Tokyo, Japan, 1977

ASANO, KIYOSHI & KOTORA HATAI
1967. Micro- and macropaleontological Tertiary correlations within Japanese Islands and with planktonic foraminiferal sequences of foreign countries. *In* K. HATAI (ed.): Tertiary correlation and climatic changes in the Pacific. 11th Pacif. Sci. Congr. Symp. 25, Tokyo: 77-87

CHINZEI, KIYOTAKA
1961. Molluscan fauna of the Pliocene Sannohe Group of Northeast Honshu, Japan: 2. The faunule of the Togawa Formation. Journ. Fac. Sci., Sec. 2, Univ. Tokyo 13 (1): 81-131; 4 plts.
1963. Notes on historical change of Neogene molluscan assemblages in Northeast Japan. Kaseki (Fossils), Palaeont. Soc. Japan 5: 20-26 (J)
1973. Omma-Manganjian molluscan fauna in the Futatsui area of northern Akita, Japan. Trans. Proc. Palaeont. Soc. Japan, N. S. 90: 81-94; plt. 14

CHINZEI, KIYOTAKA & MUTSUHARU AOSHIMA
1976. Marine thermal structure of the Plio-Pleistocene warm water in central Japan. Journ. Fac. Sci., Sec. 2, Univ. Tokyo 19 (3): 179-203

CHINZEI, KIYOTAKA & YASUHIDE IWASAKI
1967. Paleoecology of shallow sea molluscan faunas in the Neogene deposits of Northeast Honshu, Japan. Trans. Proc. Palaeon. Soc. Japan, N. S. 67: 93-113

GLADENKOV, YURII BORISOVICH
1974. The Neogene period in the subarctic sector of the Pacific. *In* YVONNE HERMAN (ed.), Marine geology and oceanography of the Arctic seas. Springer Verlag, New York: 271-281; 3 text figs.; 3 tables

HAYASAKA, SHOZO
1956. Pliocene Mollusca from the Futaba district, Fukushima Prefecture, Japan. Saito Ho-on Kai Mus. Res. Bull. 25: 13 - 20; plt. 2
1957. Miocene marine Mollusca from the Kurosawa Formation in Akita and Iwate Prefectures, Japan. Saito Ho-on Kai Mus. Res. Bull. 26: 25 - 30
1969. Molluscan fauna of the Kukinaga Group in Tane-ga-shima, South Kyushu, Japan. Rept. Fac. Sci. (Earth Sci. & Biol.), Kagoshima Univ. 2: 33 - 52; 3 plts.

HORNIBROOK, N. DE B.
1977. The Neogene (Miocene-Pliocene) of New Zealand. Proc. 1st Congr. Pacif. Neogene Stratigr., Sci. Council & Geol. Soc. Japan: 145 - 150

IKEBE, NOBUO
1954. Cenozoic biochronology of Japan. Journ. Inst. Polytech. (G), Okasa City Univ. 1: 73 - 86

IKEBE, NOBUO, YOKICHI TAKAYANAOI, MANZO CHIJI & KIYOTAKA CHINZEI
1972. Neogene biostratigraphy and radiometric time scale of Japan; an attempt at intercontinental correlation. Pacif. Geology 4: 39 - 78

INGLE, JAMES CHESNEY, Jr. & ROBERT E. GARRISON
1976. Origin, distribution, and diagenesis of Neogene diatomites around the North Pacific rim. Abstr. 1st Congr. Pacif. Neogene Stratigr., Sci. Council & Geol. Soc. Japan: 98 - 100

ITOIGAWA, JUNJI
1960. Paleoecological studies of the Miocene Mizunami Group, central Japan. Journ. Earth Sci., Nagoya Univ. 8 (2): 246 - 300
1974. Fossil molluscan assemblages. *In* J. ITOIOAWA, H. SHIBATA & H. NISHIMOTO, Fossil shells from the Mizunami Group. Bull. Mizunami Fossil Mus. 1: 196 - 203 (J)

ITOIOAWA, JUNJI & HIROSHI SHIBATA
1973. Paleoenvironmental change and correlation based on molluscan assemblages. Mem. Geol. Soc. Japan 8: 125 - 136 (J, E)

IWASAKI, YASUHIDE
1970. The Shiobara-type molluscan fauna; an ecological analysis of fossil molluscs. Journ. Fac. Sci. Sec. 2, Univ. Tokyo 17 (3): 351 - 444; 7 plts

IWAI, TAKEHIKO
1965. The geological and paleontological studies in the marginal area of the Tsugaru Basin, Aomori Prefecture, Japan. Bull. Educ. Fac., Hirosaki Univ. 15: 1 - 68; plts. 12 - 20

KANEHARA, KINJI
1940. Neogene fossils from south Echigo. Bull. Imp. Geol. Surv. Japan 27 (2): 1 - 19; 5 plts.

KANNO, SABURO
1960. Paleontology. *In* The Tertiary system of the Chichibu Basin, Saitama Prefecture, central Japan, prt. 2. Japan Soc. Promot. Sci., Tokyo: 123 - 396; plts. 31 - 51

KANNO, SABURO & KYUYA MATSUNO
1960. Molluscan fauna from the "Chikubetsu Formation," Hokkaido, Japan. Journ. Geol. Soc. Japan 66 (772): 35 - 45; plts. 4, 5

KANNO, SABURO & HISASHI OGAWA
1964. Molluscan fauna from the Momijiyama and Takinoue District, Hokkaido, Japan. Sci. Rept. Tokyo Kyoiku Daigaku, Sec. C. 81: 269 - 294; 4 plts.

KANNO, SABURO, SAKAE OHARA & HITOSHI KAITEYA
1968. The "Asahi Fauna" from the Miocene formation developed near the Asahi Coal-mine. Iwamizawa City, Hokkaido. Sci. Rept. Tokyo Univ. Educ. Sec. C 10 (94): 1 - 14; 2 plts.

KIKUCHI, TAIJI
1977. Ecological distribution of macrobenthos and shell remains off Tsuyazaki, Fukuoka Prefecture. Benthos Res. 13/14: 7 - 16 (J)

KIM, BONO KYUN, HIROSHI NODA & SUN YOON
1974. Molluscan fossils from the Miocene Eoil Formation, Gampo and Ulsan Districts, southeastern side of Korea. Trans. Proc. Palaeont. Soc. Japan N. S. 93: 266 - 285; plts. 38, 39

KOBAYASHI, TEIICHI & MASUOKI HORIKOSHI
1958. Indigenous *Aturia* and some tropical gastropods from the Miocene of Wakasa in West Japan. Japan. Journ. Geol. Geogr. 29 (1/3): 45 - 54; plts. 4, 5

KOIZUMI, ITARU
1977. Deep sea sediments and the history of Japan Sea. Kagaku, Iwanami Book Co., Tokyo 47 (1): 45 - 51 (J)

KOTAKA, TAMIO
1958. Faunal consideration of the Neogene invertebrates of northern Honshu, Japan. Saito Ho-on Kai Mus. Res. Bull. 27: 38 - 44
1959. The Cenozoic Turritellidae of Japan. Sci. Rept. Tohoku Univ. (2) 31 (2): 1 - 135; 15 plts.

MACNEIL, FRANCIS STEARNS
1960. Tertiary and Quaternary gastropods of Okinawa. U. S. Geol. Surv. Prof. Paper 339: 1 - 148; 21 plts.

MAIYA, SEIJURO
1977. Late Cenozoic planktonic foraminiferal biostratigraphy of the oil-field region of Northeast Japan. Prof. N. Ikebe Memorial volume Osaka (in press) (J, E)

MAKIYAMA, JIRO
1926. Tertiary fossils from North Kankyo-do, Korea. Mem. Coll. Sci., Ser. B, Kyoto Imp. Univ. 2 (3): 143 - 160; plts. 12, 13
1931. Stratigraphy of the Kakegawa Pliocene in Totomi. Mem. Coll. Sci., Ser. B, Kyoto Imp. Univ. 7 (1): 1 - 53
1934. The Asagaian molluscs of Yotukura and Matchgar. Mem. Coll. Sci., Ser. B, Kyoto Imp. Univ. 10 (2): 121 - 167; plts. 3 - 7
1936. The Meisen Miocene of North Korea. Mem. Coll. Sci., Ser. B, Kyoto Imp. Univ. 11 (4): 193 - 228; plts. 4, 5

MASUDA, KÔICHIRÔ
1962 . Notes on the Tertiary Pectinidae of Japan. Sci. Rept. Tohoku Univ. (2) (Kon'no Mem. vol.) 5: 159 - 193; 9 text figs.
1966. Molluscan fauna of the Higashi-Innai Formation of Noto Peninsula, Japan; 1. A general consideration of the fauna. Trans. Proc. Palaeont. Soc. Japan, N. S. 63: 261 - 293
1973. Molluscan biostratigraphy of the Japanese Neogene. Mem. Geol. Soc. Japan 8: 107 - 120; 2 plts.; 1 text fig. (J, E)

NODA, HIROSHI
1966. The Cenozoic Arcidae of Japan. Sci. Rept. Tohoku Univ. (2) 38 (1); 1 - 161; 14 plts.
1976. Preliminary notes on the bathyal molluscan fossils from the Shinzato Formation, Okinawa-jima, Okinawa Prefecture, Southwestern Japan. Ann. Rept. Inst. Geosci., Univ. Tsukuba 2: 40 - 41

NOMURA, SITIHEI
1935. On some Tertiary Mollusca from Northeast Honshu, Japan: pt. 2. Fossil Mollusca from the vicinity of Ogino, Yama-Gun, Hukushima-Ken. Saito Ho-on Kai Mus. Res. Bull. 5: 101 - 125; plst. 5 - 7

OGASAWARA, KENSHIRO
1977. Paleontological analysis of Omma Fauna from Toyama-Ishikawa area, Hokuriku Province, Japan. Sci. Rept. Tohoku Univ. (2) 47 (2): 43 - 156; plts. 3 - 22

OHARA, SAKAE & SABURO KANNO
1973. Mid-Tertiary marine molluscan faunas from the Uryu Coal-field of central Hokkaido, Japan. Sci. Rept. Tohoku Univ. (2) Spec. vol. 6: 125 - 135

OKAMOTO, KAZUO
1970. Tertiary formations in the area around Kottoi-harbor, Hohokumachi, Toyoura-gun, Yamaguchi Prefecture, with reference to the molluscan fossil assemblages and sedimentary environment of the Hioki Group. Journ. Geol. Soc. Japan 76 (5): 235 - 246 (J, E)

OKUTANI, TAKASHI
1972. The probable subarctic elements found in the bathyal megalobenthos in Sagami Bay. Journ. Oceanogr. Soc. Japan 28 (3): 95 - 102

OTUKA, YANOSUKE
1934. Tertiary structures of the northwestern end of the Kitakami Mountainland, Iwate Prefecture, Japan. Bull. Earthq. Res. Inst., Univ. Tokyo 12 (3): 566 - 638; plts. 44 - 51
1936. Pliocene Mollusca from Manganzi in Kotomo-mura, Akita Pref., Japan. Trans. Proc. Palaeont. Soc. Japan. Old Ser. 4 (*in* Journ. Geol. Soc. Japan 43): 726 - 736; plts. 41, 42
1939. Tertiary crustal deformations in Japan; with short remarks on Tertiary palaeogeography. Jubl. Publ. Commem. Prof. H. Yabe's 60th Birthday: 481 - 519
1941. Neogene fossil fauna between Honjo and Kurosawajiri. Journ. Japan Assoc. Petrol. Technologists 9 (2): 147 - 157 (J)

OYAMA, KATURA
1950. Studies of fossil molluscan biocoenosis, No. 1; biocoenological studies on the mangrove swamps, with descriptions of new species from Yatuo Group. Geol. Surv. Japan, Rept. 132: 1 - 16; 3 plts.

OZAKI, HIROSHI
1958. Stratigraphical and paleontological studies on the Neogene and Pleistocene formations of the Choshi District. Bull. Natl. Sci. Mus. 4 (1): 1 - 182; 24 plts.

PETERSEN, C. G. J.
1913. Valuation of the sea II: The animal communities of the sea-bottom and their importance for marine zoogeography. Rept. Danish Biol. Stat. 21: 1 - 44; 6 plts., 3 charts

SANDERS, HOWARD L.
1958. Benthic studies in Buzzards Bay; I, animal-sediment relationships. Limnol. Oceanogr. 3(3): 245 - 258

SHACKELTON, NICHOLAS J. & JAMES P. KENNETT
1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP sites 277, 279, and 281. *In* J. P. KENNETT, R. E. HOUTZ *et al.*, Init. Rept. Deep Sea Drill. Proj., Washington, 29 (17): 743 - 755

SHIKAMA, TOKIO
1973. Molluscan assemblages of the basal part of the Zushi Formation in the Miura Peninsula. Sci. Rept. Tohoku Univ. (2) Spec. vol. 6: 179 - 204; plts. 16, 17

SHIKAMA, TOKIO & TOMOKI KASE
1976. Molluscan fauna of the Miocene Morozaki Group in the southern part of the Chita Pcninsula, Aichi Prefecture, Japan. Sci. Rept. Yokohama Natl. Univ. Sec. 2, 23: 1 - 25; 2 plts.

SHUTO, TSUGIO
1961. Palaeontological study of the Miyazaki Group; a general account of the faunas. Mem. Fac. Sci. Ser. D., Kyushu Univ. 10 (2): 73 - 206; plts. 11 - 13
1963. Geology of thc Nichinan area with special reference to the Takachiho Disturbance. Sci. Rep. Fac. Sci. (Geol.), Kyushu Univ. 6 (2): 135 - 166; plts. 14 - 18 (J, E)

SHUTO, TSUGIO & NARUMI SHIRAISHI
1971. A note on the community-paleoecology of the Ashiya Group. Sci. Rept. Fac. Sci. (Geol.), Kyushu Univ. 10 (3): 253 - 270 (J, E)

TAI, YOSHIRO
1963. Historical change of Neogene foraminiferal assemblages in the Setouchi-Sanin areas and Foram. Sharp Line. Kaseki (Fossils), Palaeont. Soc. Japan 5: 1 - 7 (J)

THORSON, GUNNAR
1957. Bottom communities (sublittoral or shallow shelf). *In*: J. W. HEDGPETH (ed.): Treatise on Marine Ecology and Paleoecology 1, Geol. Soc. Amer. Mem. 67: 461 - 534

TSUCHI, RYUICHI
1960. Late Neogene sediments and molluscs in the Tokai region, with notes on the geologic history of Southwest Japan. Japan. Journ. Geol. Geogr. 32 (3, 4): 437 - 456

TSUDA, KARYU
1960. Paleo-ecology of the Kurosedani Fauna. Journ. Fac. Sci. Ser. 2, Niigata Univ. 3 (4): 171 - 203

UOZUMI, SATORU
1962. Neogene molluscan faunas in Hokkaido (Part 1: Sequence and distribution of Neogene molluscan faunas). Journ. Fac. Sci. Ser. 4 4, Hokkaido Univ. 11 (3): 507 - 544
1966. Neogene molluscan fauna in Hokkaido; pt. 1, Description of the Asahi fauna associated with *Mytilus tichanovitchi* Makiyama, from Ikushunbetsu district, central Hokkaido. Journ. Fac. Sci. Ser 4, Hokkaido Univ. 13 (2): 119 - 137; plts. 9, 10

UOZUMI, SATORU & TSUTOMU FUJIE
1966. Neogene molluscan fauna in Hokkaido; pt. 2, Description of the Okushiri fauna associated with *Vicarya*, from Okushiri Island, Southwest Hokkaido. Journ. Fac. Sci. Ser. 4, Hokkaido Univ. 13 (2): 139 - 163; plts. 11 - 13

YOKOYAMA, MATAJIRO
1920. Fossils from the Miura Peninsula and its immediate North. Journ. Coll. Sci., Imp. Univ. Tokyo 39 (6): 1 - 193; 20 plts.
1923. On some fossil shells from the Island of Saishu in the Straits of Tsushima. Journ. Coll. Sci., Imp. Univ. Tokyo 44 (7): 1 - 9; 1 plt.
1926. Tertiary Mollusca from Shiobara in Shimotsuke. Journ. Fac. Sci. Sec. 2, Imp. Univ. Tokyo 1 (4): 127 - 138; plts. 16 - 20